ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if
Reproduced in Whole or in Part

To Mr. M.J. Nichols
Manager - Central Nuclear Service Department
Technical and Training Services Division

SINGLE FUEL CHANNEL REPLACEMENT - B2N06

M. Cenanovic, M. Ng, T. Malkiewicz, J. Lee

ABSTRACT

Following the rupture of the pressure tube and calandria tube (C/T) in Unit 2 of Bruce "A" NGS (B2N06) on March 28, 1986, a development program for calandria tube/tubesheet (C/T-T/S) rolled joint separation using shock heating was initiated. The separation process was complicated by field inspection results which revealed the existence of a circumferential crack on one of the rolled joint inserts.

A shock heating process for separating undamaged C/T rolled joints was developed, which satisfied the constraints imposed by the presence of the crack, and was successfully demonstrated in the Ontario Hydro Research Laboratory and Bruce "A" NGS. A decision was then made to proceed with this technique to separate the C/T rolled joints of channel B2N06. With the joint efforts of Ontario Hydro Research and Bruce "A" NGS staff, C/T inserts were separated from the B2N06 channel on May 20 and 21, 1986, and the C/T was removed from the channel on May 23, 1986. This report describes the programs carried out at both Ontario Hydro Research and Bruce "A" NGS for the successful implementation of the shock heating technique for the separation of C/T rolled joints of channel B2N06.

1. BACKGROUND

The shock heating process for separation of rolled joints was developed at the Ontario Hydro Research Laboratory in anticipation of potential single and large scale fuel channel replacement in CANDU reactors. This process was successfully used for separation of the undamaged C/T rolled joints at Pickering "A" NGS following the failure of the pressure tube in channel P2G16 in 1983/1/. A version of this process was developed and successfully used for large scale fuel channel replacement at Pickering "A" NGS Units 1 and 2/2/.

The development of this process for separation of Bruce-type C/T rolled joints was delayed due to concurrent high priority work on the large scale fuel channel replacement program. Following the sudden need for this process at Bruce "A" NGS for channel B2N06, a development program was initiated at Ontario Hydro Research Laboratory to demonstrate feasibility of the shock heating process for separation of the damaged C/T at Bruce "A" NGS/3/.

A shock heating process was developed to meet the objectives described below under the imposed technical and time constraints.

job	file	date	report no.
740615-139-103	823.45	December 16, 1988	88-336-K

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

2. OBJECTIVES, PROCESS AND CONSTRAINTS

The objective was to develop a simple and reliable process for the separation of calandria tube rolled joints without any adverse effect on the tubesheet so that it can be readily reused. This requires sufficient reduction in diameters of the C/T and C/T insert to allow easy removal of the damaged C/T through the tubesheet bore at either end of the reactor channel.

The shock heating process makes use of the induction heating principle whereby the induction coil is positioned inside the work piece (i.e. the C/T rolled joint). A magnetic field produced by alternating current in the coil, in turn produces eddy currents in a shallow layer of the C/T insert. The thickness of the layer is controlled by the frequency of the electromagnetic field. For this particular process, a frequency of 125 kHz was selected to achieve a desired temperature gradient in the radial direction. This gradient is generated by the eddy currents that heat the work piece as a result of I^2R losses, where "I" is the current and "R" is the resistance of a shallow tubular layer of the work piece.

The basic principle for reducing the C/T and C/T insert diameter can be explained as follows:

> When a C/T insert and a C/T heat up rapidly, they tend to expand against the tubesheet. Since the tubesheet is colder and much more massive, the C/T insert and C/T can not expand radially. The heating energy is then stored elastically in the C/T insert and C/T until the high-frequency energy source is switched off. This stored energy is then released in a form which contracts the C/T insert and the C/T radially, thus creating a radial gap between the C/T insert, C/T and tubesheet.

The main constraints for the separation of the undamaged C/T rolled joint are:

a) The metallurgical transformation temperature of the tubesheet material (622°C) can not be exceeded.
b) The melting temperature of the C/T insert should not be approached.

For the damaged C/T and C/T insert of channel B2N06, the following are additional constraints:

c) The axial split of the C/T protruded all the way to the tubesheet (Figure 1).
d) Furthermore, there was a radial partial crack of the C/T insert at the East End of channel B2N06 (Figure 2).

3. DEVELOPMENT PROGRAM AT ONTARIO HYDRO RESEARCH LABORATORY

To shorten the development time and retain reliability of the separation process, the shock heating system and process which were developed for Pickering "A" NGS for separating C/T-T/S rolled joints of channel P2G16 were modified and improved. Modification was necessary since there is a difference in geometry between the reactor channels of Pickering "A" NGS and Bruce "A" NGS and there was an additional requirement to reduce the diameter of the C/T for easy removal through the tubesheet bore/4,5,6,7,8/.

The initial work was carried out at the Ontario Hydro Research Laboratory. Ontario Hydro Research (OHR) requested the return of the 160-kW Shock Heating System used for the separation of C/T-T/S rolled joints of channel P2G16 at Pickering "A" NGS in 1983 to the OHR Electromagnetic Laboratory/9/. Although originally intended as a standby technique, it soon became evident that only the shock heating technique was suitable for removal of the split calandria tube/10/.

Figure 1 *A Simulated Split Calandria Tube*

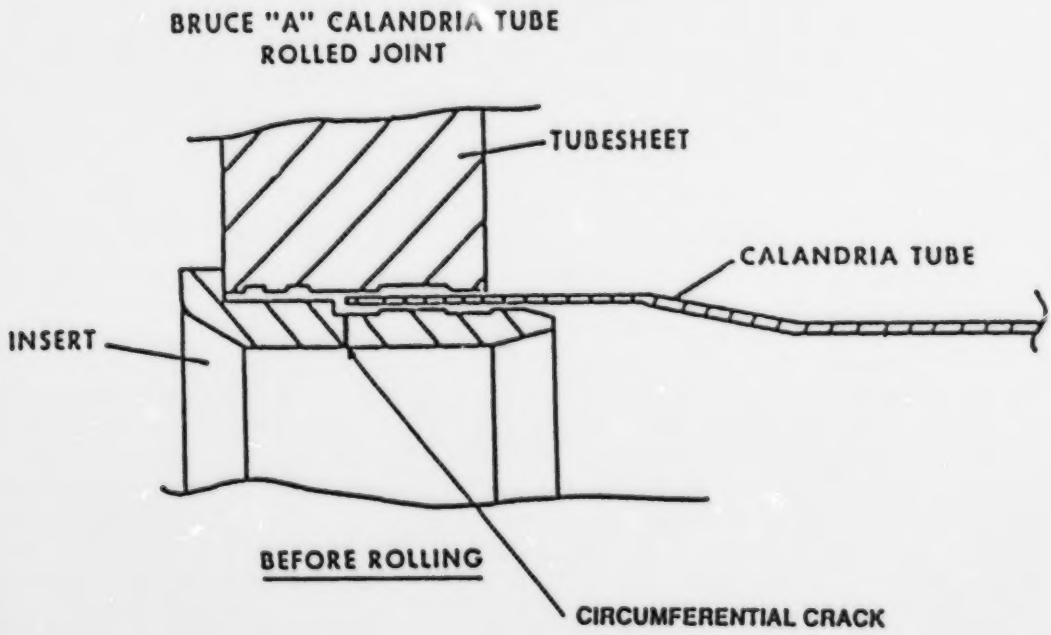

Figure 2 *Cross-section of Bruce "A" Calandria Tube Rolled Joint*
(Note: circumferential crack of the calandria tube insert)

3.1 Hardware

The main components of the shock heating system are:

- dc power supply
- oscillator tube section
- load coil transformer
- transmission line and positioning system
- induction coil (Figure 3)
- cooling system
- computer control system.

***Figure 3** Induction Coil for Shock Heating*

Due to differences in geometry between the fuel channels of Pickering "A" NGS and Bruce "A" NGS, the hardware had to be modified. The modifications included the following:

a) Redesign the induction heating coil radial centering system for the Bruce channel geometry,
b) Redesign the induction heating coil axial positioning system to cope with the variations in the Bruce channel geometry. A pair of rods, originally designed to retain the loosened inserts in the rolled joint after shock heating/11/ were utilized as axial positioning and measuring devices,
c) Redesign the load coil transformer and transmission line supporting system to regulate the power transfer between these two components,
d) Redesign the cabling between the dc power supply and the oscillator tube section. This allows the dc power supply and the operator work station to be located outside the reactor vault.

These modifications were experimentally verified on the fuel channel mockup in the laboratory (Figure 4). The improved hardware insured reliability and consistency of the coil positioning system and therefore of the rolled joint separation process.

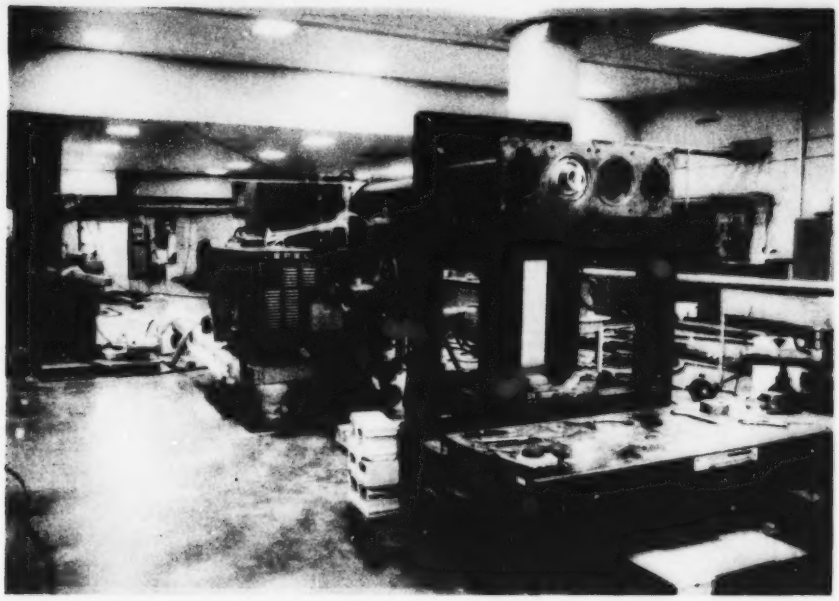

***Figure 4** Shock Heating Test Setup at the Ontario Hydro Research Laboratory*

3.2 Software

The control software for induction heating cycles which was used for single fuel channel replacement program of channel P2G16 at Pickering "A" NGS was modified to accommodate the Bruce-type C/T-T/S rolled joint separation process requirements. The modifications included the heating and cooling control system and the operator-machine interface.

A copy of the modified control software is attached in Appendix I. Details of the computer system are described in Reference 12.

3.3 Process Parameters

To reduce the development time, the shock heating process parameters previously developed were modified to allow for natural cooling. It was also required that the shrinkage of the C/T be optimized to accommodate for easy removal of the cracked C/T from the channel/13/. Various heating cycle configurations were investigated to fulfill the requirement. A shock heating procedure was determined as outlined below:

Activity	Duration
Warm up cycle	10 sec.
First power cycle	33 sec.
Second power cycle	23 sec.

Two power cycles were necessary to separate the C/T rolled joint.

4. SIMULATIONS

4.1 Simulation of Cracks

Following N06 channel inspections, it was found that the East end insert was cracked circumferentially and the C/T was cracked longitudinally through the "bell area" at both East and West ends of the channel. A program was initiated at the laboratory to investigate the influence of cracks on the shock heating process.

Results indicated that cracks on the insert and the C/T could be tolerated by the shock heating process/14,15,16/.

4.2 Water Entrapped in C/T Rolled Joint

From past experience, it was found that water trapped between the pressure tube and the end fitting rolled joint would cause damage to the pressure tube upon application of the shock heating cycles. Tests with water injected into the C/T rolled joint were conducted to investigate the possibility of the C/T being damaged by entrapped water which may be present in the C/T rolled joints of channel B2N06. No damage was observed.

5. PROGRAM AT BRUCE SITE

Due to time constraints, it was necessary to speed up the implementation of the shock heating process at Bruce "A" NGS (Figure 5). A program was outlined and carried out at site by Ontario Hydro Research staff with support and coordination provided by the Station staff. The main objective of the program was to integrate the shock heating process into the station repair program for channel B2N06, while waiting for the completion of station activities preceding the actual calandria tube removal. These activities consisted of the following:

- equipment layout at site mockup area/17,18/
- commissioning of the shock heating system
- purchasing and manufacturing of spare parts
- training of the station repair crew
- simulation of the shock heating process on the full length cracked calandria tube
- integration of shock heating system with other channel repair tooling
- safety
- documentation
- preparation of on-reactor procedure and equipment layout.

6. ON-REACTOR

Following the completion of all preceding activities related to the repair of channel B2N06, the actual separation of the C/T rolled joints and removal of the calandria tube were carried out as planned.

In order to keep the dc power supply and all computer control of the shock heating equipment outside the reactor vault, a long (100 m) cable assembly was installed through the penetration EP1057.

The repair went without major problems with the shock heating equipment (Figure 6). The trial sample joints were shock heated first and came apart very easily. Then the actual channel repair took place. As expected, the insert removal did not damage the tubesheet bores and the split C/T was successfully pushed through the East End tubesheet bore. The removal was completed on May 23, 1986, 56 days following the failure of channel B2N06.

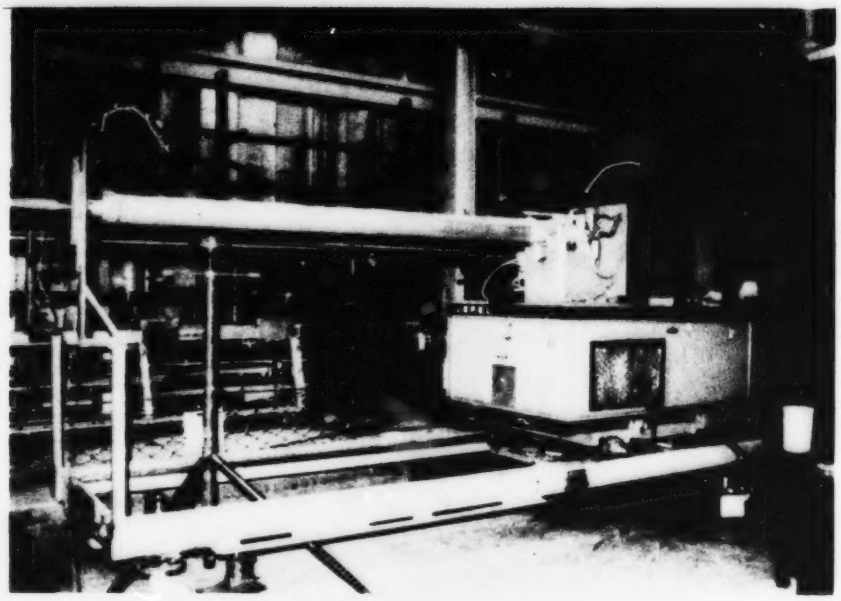

Figure 5 Shock Heating Test Setup at Bruce "A" NGS Mock-up Area

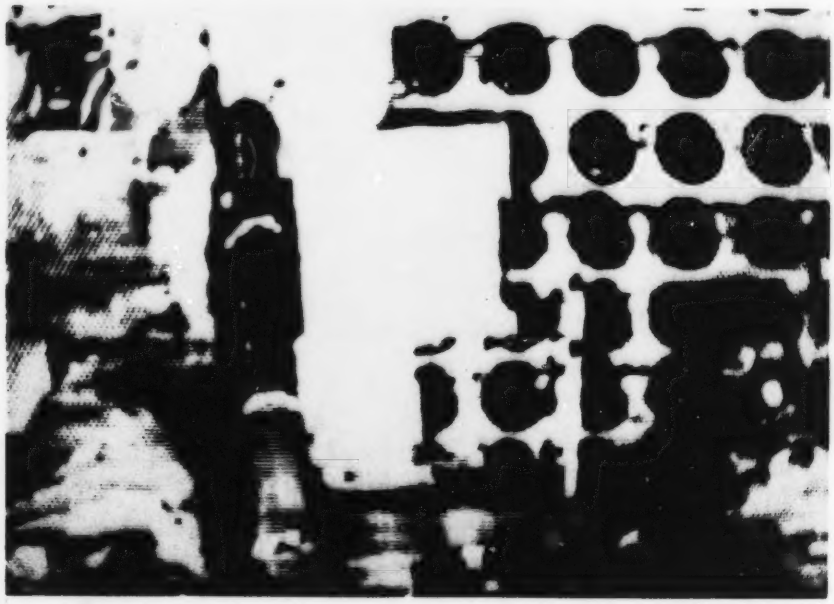

Figure 6 Insertion of the Induction Heating System into Channel B2N06

7. CONCLUSIONS

The shock heating process was developed and proven capable of separating Bruce-type C/T rolled joints. The process reduced the C/T diameter making removal of a damaged C/T possible without requiring any significant mechanical forces. The initial development of this process started as an anticipatory research effort. The successful implementation of this process was achieved in a very short period of time, through cooperation between Research, Station staff and Head Office staff.

The significance of this development is that the process is suitable for both Pickering and Bruce-type C/T rolled joints as demonstrated at Pickering 'A' NGS (channel P2G16) and Bruce 'A' NGS (channel B2N06). Also, in the case of the channel B2N06, the process had proven its flexibility in adapting itself to unexpected field conditions.

8. RECOMMENDATIONS AND FUTURE OUTLOOK

Presently, the thrust of the development of the existing shock heating system is to enable the two existing 250-kW sets to be readily used for SFCR of C/T for both Bruce and Pickering stations/19,20,21,22,23/. This work is ongoing and will be reported in a separate Research Division Report to NSD, which is funding this effort.

Future research is recommended to optimize (Appendix II) the process and minimize the induction heating equipment for robotic handling in future reactor maintenance and rehabilitation/24,25,26/.

Recommended:

G.L. Ford
Supervising Engineer
Stations & Underground Section
Electrical Research Department

Submitted:

M. Cenanovic
Senior Research Engineer
Electrical Research Department

M. Ng, T. Malkiewicz, J. Lee

Engineers
Stations & Underground Section
Electrical Research Department

Approved:

A.F. Baljet
Manager
Electrical Research Department

References

1) Report from Mr. M. Cenanovic to Mr. Z.J. Janik, "Instruction Manual For Induction Heating System For Separation Of Calandria Tube Rolled Joints", September 21, 1983, report no. 83-403-H.

2) Report from Mr. M. Cenanovic, Mr. M. Ng & Mr. H. Maureira to Mr. H.C. Mahon, "Rapid Induction Heating For Separation Of Rolled Joints - Phase I", February 14, 1986, report no. 85-270-K.

3) Memorandum from Mr. M. Cenanovic to Mr. M. Ng and Mr. J. Lee, "Failure of B2N06 at Bruce 'A' NGS", File 823.45(P), March 31, 1986.

4) Memorandum from Mr. M. Cenanovic to Mr. B.D. MacTavish, "Status of Shock Heating for Bruce "A" NGS Unit 2, Channel N6 Replacement", File 823.45(P).

5) Memorandum from Mr. M. Cenanovic to Mr. B.D. MacTavish, "Shock Heating for B2N6 Replacement, Progress Report No. 2", April 8, 1986, File 823.45(P).

6) Memorandum from Mr. A.F. Baljet to Mr. I.E.B. Lauchlan, "Organization for Research Involvement in Shock Heating Repair of B2 N06", File 823.45(T), April 11, 1986.

7) Memorandum from Mr. M. Ng, Mr. J. Lee & Mr. T. Malkiewicz to Mr. B.D. MacTavish, "Shock Heating for B2N06 Replacement, Progress Report No. 3", April 13, 1986, File 823.45(P).

8) Minutes of Meeting prepared by Mr. J. Lee, "Minutes of Meeting, B2N06 SFCRP", April 17, 1986, File 823.45(P).

9) Memorandum from Mr. C. Marshall to Mr. M. Cenanovic, "Availability of 160 kW Induction Heater", April 9, 1986, File 823.45(P).

10) Memorandum from Mr. M. Cenanovic to Mr. B. Dicks, "B2N06 SFCRP Shock Heating - Phase II", April 21, 1986, File 823.45(P).

11) Addendum to report from Mr. M. Cenanovic to Mr. Z.J. Janik, "Instruction Manual for Induction Heating System for Separation of Calandria Tube Rolled Joints", Sept. 26, 83, File 823.45(P).

12) Report from Mr. M. Ng to Mr. Z.J. Janik, "Control And Monitoring System for Fast Induction Heating Equipment", April 22, 1986, report no. 85-60-K.

13) Telex from Mr. J.H. Erven to Mr. M. Cenanovic, "Bruce GS A N6 Outage - Shock Heating System", April 11, 86, Telex 91.

14) Memorandum from Mr. J. Lee to Mr. M. Cenanovic, "SFCRP crack simulation test for B2N06", May 6, 1986, File 825.45(P).

15) Memorandum from Mr. J. Lee to Mr. M. Cenanovic, "SFCRP crack simulation Test II for B2N06", May 10, 1986, File 825.45(P).

16) Memorandum from Mr. J. Lee to Mr. M. Cenanovic, "SFCRP insert crack simulation for B2N06", May 20, 1986, File 823.45(P).

17) Memorandum from Mr. T. Malkiewicz to Mr. W.S. Martynowicz, "Shock Heating Equipment for Bruce "A" NGS Unit 2, Channel No 6 Removal", April 10, 1986, File 823.45(P).

18) Memorandum from Mr. W.S. Martynowicz to Mr. H. Cassis, "Bruce Unit '2' N6, Service Requirements/Equipment Layout for Shock Heating", April 10, 1986, File 907-21SC-60403-T3.

19) Memorandum from Mr. M. Cenanovic to Dr. G.L. Ford, "Nuclear Reactor Rehabilitation Programs", File 823.45(P), February 25, 1988.

20) Memorandum from Mr. M. Ng, Mr. T. Malkiewicz and Mr. J. Lee to Mr. M. Cenanovic, "Single Fuel Channel Replacement Program (SFCRP) Calandria Tube - Rolled Joint Separation OHR Program Proposal", File 823.45(P), March 8, 1988.

21) Minutes of Meeting from Mr. T. Malkiewicz, "Nuclear Reactors Rehabilitation Program / SFCRP", File 823.45(P), April 11, 1988.

22) Memorandum from Mr. J. Morcom to Mr. M. Cenanovic, "SFCRP Calandria Tube Rolled Joint Separation OHR Proposal March 8, 1988", April 14, 1988.

23) Memorandum from Mr. M. Cenanovic to Mr. J. Morcom, "Single Fuel Channel Replacement Program Calandria Tube Rolled Joint Separation Priority 1 Program", File 823.45(P), April 28, 1988.

24) Memorandum from Mr. M. Ng, Mr. T. Malkiewicz & Mr. J. Lee to Mr. M Cenanovic, "SFCRP - Optimization of the Shock Heating Technique for C/T rolled joint separation", November 13, 1986, File 823.45(P).

25) Memorandum from Mr. M. Cenanovic to Mr. R. Arnold, "Calandria Tube Replacement Tooling B2-N06 Post Mortem", November 17, 1986, File 823.45(P).

26) Memorandum from Mr. M. Ng to Mr. M. Cenanovic, "LSFCRP & SFCRP - Optimization", May 6, 1987, File 823.45(P).

APPENDIX I

SHOCK HEATING SYSTEM CONTROL SOFTWARE (WARMUP CYCLE)

```
 21 PRINT "SINGLE CHANNEL REFL P
    ROGRAM"
 22 PRINT "----------------------
    ------"
 23 PRINT "COMPUTER CONTROL SYST
    EM IS ON"
 24 PRINT " " @ PRINT " "
 25 PRINT "DATE:"
 26 PRINT "TIME:"
 27 PRINT "CHANNEL # :"
 28 PRINT "WARM UP CYCLE"
 29 REM ON ERROR GOSUB 7000
 30 REM ON TIMEOUT 7 GOTO 2000
 40 REM SET TIMEOUT 7;1000
 41 PRINT " " @ PRINT " "
 42 DIM T(7,71)
 43 P1=61
 45 P2=10
 46 W2=P2+.5
 47 PRINT "POWER SETTING =    ";P
    1
 48 PRINT "DURATION =    ";P2
 49 J=1
 50 A1=709
 55 A2=704
 56 F1=0
 57 F2=0
 58 CLEAR
 60 DISP "SCANNER - SELF TEST ST
    ARTS"
 70 OUTPUT A1 ;"ST1"
 80 ENTER A1 ; B$
 90 IF B$<>"8E8" THEN GOTO 120
100 DISP "SCANNER - SELF TEST PA
    SSED"
110 GOTO 180
120 IF B$="1E1" THEN DISP "CROSS
     GUARD FAILED"
130 IF B$="2E2" THEN DISP "A/D F
    AILED"
140 IF B$="3E3" THEN DISP "HP349
    7A TIMER FAILED"
150 DISP "DO YOU WANT TO CHECK A
    GAIN ? (Y/N)"
160 INPUT A$
170 IF A$="Y" THEN GOTO 50
175 GOTO 6654
180 GOSUB 2020
182 OUTPUT 709 ;"DO2,0,1,2,3"
200 GOSUB 2000
210 DISP " "
220 DISP "HEATING CYCLE PARAMETE
    RS:"
240 DISP "POWER SETTING =";P1
250 DISP "DURATION = ";P2
260 A$="N"
270 DISP "DO YOU WANT TO START T
    HE HEATING CYCLE ? (Y/N)"
280 INPUT A$
290 IF A$="Y" THEN GOTO 305
300 GOTO 6654
305 F1=0 @ J=1
306 GOSUB 2700 @ T(7,1)=0
307 PRINT "TURN POWER ON"
308 WAIT 2000
310 GOSUB 3000
320 X=2000
330 OUTPUT 714 USING "#,4D" ; X
335 F1=1
340 S=P1/30
345 BEEP @ BEEP
346 OUTPUT 709 ;"DC2,0"
347 WAIT 10
348 OUTPUT 709 ;"DO2,0"
350 SETTIME 0,0
360 FOR I=1 TO P1 STEP S
370 X=2000+I
380 OUTPUT 714 USING "#,4D" ; X
390 NEXT I
400 A=TIME
410 L1=(P2-A)*1000
420 ON TIMER# 1,L1 GOSUB 2920
430 L2=L1+300
440 ON TIMER# 2,L2 GOSUB 2910
450 FOR J=2 TO 70
460 T(7,J)=TIME
470 GOSUB 2700
490 B=TIME
500 IF B>W2 AND F1<>0 THEN GOSUB
     2900
505 PLOT T(7,J),T(2,J)
510 NEXT J
514 W=70
515 GOTO 6500
520 END
2000 PRINT "COMPUTER INTERFACE F
     AILED"
2005 PRINT "TURN POWER OFF AND S
     E
```

```
2017 IF F2=10 THEN GOTO 2920
2020 U=2000
2030 OUTPUT 714 USING "#,4D" ; U
2040 PRINT "TURN POWER OFF"
2042 BEEP @ BEEP
2045 IF F2=10 THEN GOTO 6500
2046 F1=0
2047 OUTPUT 709 ;"DC2,2"
2048 WAIT 10
2049 OUTPUT 709 ;"DO2,2"
2050 RETURN
2500 CLEAR
2510 DISP "FAST INDUCTION HEATIN
     G SYSTEM   CONDITIONS"
2520 DISP "PLATE CURRENT = ";T(1
     ,J)
2530 DISP "GRID CURRENT = ",T(2,
     J)
2560 DISP "PLATE VOLTAGE = ";T(4
     ,J)
2590 REM DISP "RF POWER = ",T(6,
     J)
2600 RETURN
2700 OUTPUT A1 ;"VR5"
2710 OUTPUT A1 ;"AI38"
2720 ENTER A1 ; T(4,J)
2730 OUTPUT A1 ;"AI36"
2740 ENTER A1 ; T(2,J)
2770 OUTPUT A1 ;"AI35"
2780 ENTER A1 ; T(1,J)
2820 REM ENTER A2 ; C$
2821 REM T(6,J)=VAL(C$)
2830 GOSUB 4000
2870 RETURN
2900 DISP "HP85 TIMER 2 NOT FUNC
     TIONING"
2910 DISP "HP85 TIMER 1 NOT FUNC
     TIONING"
2920 OFF TIMER# 1
2930 OFF TIMER# 2
2940 GOTO 2020
3000 GCLEAR
3005 SCALE -6,60,-.3,3
3010 XAXIS 0,2
3020 YAXIS 0,.3
3025 MOVE 3,22.5/25*3
3026 LDIR 0
3027 LABEL "SINGLE CHANNEL REPL
     PROGRAM"
3028 MOVE 3,21.9/25*3
3029 LDIR 0 @ LABEL "----------
     ----------"
3050 LABEL "TIME (0-60 SEC)"
3060 MOVE -4,1/25*3
3070 LDIR 90
3080 LABEL "GRID CURRENT (0-3A)"
3090 MOVE P2+1,0
3091 LDIR 90
3093 LABEL "----------"
3110 PLOT T(7,1),T(2,1)
3120 RETURN
4000 T(1,J)=INT(T(1,J)*3500 .005
     28*3.4/3.1)/1000
4010 T(2,J)=INT(T(2,J)*510/ 0207
     *2)/1000
4030 T(4,J)=INT(T(4,J)*5000/.010
     47)/1000
4050 REM T(6,J)=T(6,J)/10
4053 IF T(1,J)<.49 THEN T(1,J)=0
4054 IF T(2,J)<.17 THEN T(2,J)=0
4055 IF T(4,J)<.69 THEN T(4,J)=0
4056 REM IF T(6,J)<.25 THEN T(6,
     J)=0
4057 RETURN
6500 IF J=71 THEN J=70
6505 W=J
6510 IF J=1 THEN GOTO 6654
6514 PRINT " "
6530 PRINT "TIME (S)     PL VO
       PL.CU "
6540 FOR I=1 TO W
6550 PRINT T(7,I);"   ";T(4,I);"
       ";T(1,I)
6560 NEXT I
6565 PRINT " "
6570 PRINT "GRID CU."
6580 FOR I=1 TO W
6590 PRINT T(2,I)
6600 NEXT I
6610 PRINT " "
6620 GRAPH
6630 COPY
6654 PRINT " "
6655 PRINT "COMPUTER CONTROL SYS
     TEM IS OFF !"
6660 END
7000 DISP "TURN POWER OFF"
7005 U=2000
7006 OUTPUT 714 USING "#,4D" ; U
7010 PRINT "ERROR NUMBER = ";ERR
     N
7020 PRINT "ERROR STATEMENT LINE
      NO. =";ERRL
7030 OFF ERROR
```

SHOCK HEATING SYSTEM CONTROL SOFTWARE (FIRST POWER CYCLE)

```
 19 REM SINGLE CHANNEL REPLACE-
 20 REM MENT PROGRAM
 21 PRINT "SINGLE CHANNEL REPL P
    ROGRAM "
 22 PRINT "----------------------
    ------"
 23 PRINT "COMPUTER CONTROL SYST
    EM IS ON"
 24 PRINT " " @ PRINT "
 25 PRINT "DATE:"
 26 PRINT "TIME:"
 27 PRINT "CHANNEL # :"
 28 PRINT "1 st POWER CYCLE"
 29 REM ON ERROR GOSUB 7000
 30 REM ON TIMEOUT 7 GOTO 2000
 40 REM SET TIMEOUT 7;1000
 41 PRINT " " @ PRINT " "
 42 DIM T(7,71)
 43 P1=121
 45 P2=28
 46 W2=P2+.5
 47 PRINT "POWER SETTING =    ",P
    1
 48 PRINT "DURATION =    ";P2
 49 J=1
 50 A1=709
 55 A2=704
 56 F1=0
 57 F2=0
 58 CLEAR
 60 DISP "SCANNER - SELF TEST ST
    ARTS"
 70 OUTPUT A1 ;"ST1"
 80 ENTER A1 ; B$
 90 IF B$<>"8E8" THEN GOTO 120
100 DISP "SCANNER - SELF TEST PA
    SSED"
110 GOTO 180
120 IF B$="1E1" THEN DISP "CROSS
     GUARD FAILED"
130 IF B$="2E2" THEN DISP "A/D F
    AILED"
140 IF B$="3E3" THEN DISP "HP349
    7A TIMER FAILED"
150 DISP "DO YOU WANT TO CHECK A
    GAIN ? (Y/N)"
160 INPUT A$
170 IF A$="Y" THEN GOTO 50
175 GOTO 6654
180 GOSUB 2020
182 OUTPUT 709 ;"DO2,0,1,2,3"
185 I=1
190 GOSUB 2700
200 GOSUB 2500
210 DISP " "
220 DISP "HEATING CYCLE PAR
    RS:"
240 DISP "POWER SETTING =",P1
250 DISP "DURATION = ",P2
260 A$="N"
270 DISP "DO YOU WANT TO START T
    HE HEATING CYCLE ? (Y/N)"
280 INPUT A$
290 IF A$="Y" THEN GOTO 305
300 GOTO 6654
305 F1=0 @ J=1
306 GOSUB 2700 @ T(7,1)=0
307 PRINT "TURN POWER ON"
308 WAIT 2000
310 GOSUB 3000
320 X=2000
330 OUTPUT 714 USING "#,4D"
335 F1=1
340 S=F1/30
345 BEEP @ BEEP
346 OUTPUT 709 ;"DC2,1"
347 WAIT 10
348 OUTPUT 709 ;"DO2,1"
350 SETTIME 0,0
360 FOR I=1 TO P1 STEP S
370 X=2000+I
380 OUTPUT 714 USING "#,4D" ; X
390 NEXT I
400 A=TIME
410 L1=(P2-A)*1000
420 ON TIMER# 1,L1 GOSUB 2920
430 L2=L1+300
440 ON TIMER# 2,L2 GOSUB 2910
450 FOR J=2 TO 70
460 T(7,J)=TIME
470 GOSUB 2700
490 B=TIME
500 IF B>W2 AND F1<>0 THEN GOSUB
     2900
505 PLOT T(7,J),T(2,J)
510 NEXT J
514 W=70
515 GOTO 6500
520 END
2000 PRINT "COMPUTER INTERFACE F
     AILED"
2005 PRINT "TURN POWER OFF AND S
     EE MANUAL"
2010 RESET 7
```

```
2030 U=3000
2040 OUTPUT 714 USING "#,4D" ; U
2040 PRINT "TURN POWER OFF"
2042 BEEP @ BEEP
2045 IF F2=10 THEN GOTO 6500
2046 F1=0
2047 OUTPUT 709 ;"DC2,3"
2048 WAIT 10
2049 OUTPUT 709 ;"DO2,3"
2050 RETURN
2500 CLEAR
2510 DISP "FAST INDUCTION HEATIN
     G SYSTEM   CONDITIONS:"
2520 DISP "PLATE CURRENT = ",T(1
     ,J)
2530 DISP "GRID CURRENT = ",T(2,
     J)
2560 DISP "PLATE VOLTAGE = ",T(4
     ,J)
2590 REM DISP "RF POWER = ",T(6,
     J)
2600 RETURN
2700 OUTPUT A1 ;"VR5"
2710 OUTPUT A1 ;"AI38"
2720 ENTER A1 ; T(4,J)
2730 OUTPUT A1 ;"AI36"
2740 ENTER A1 ; T(2,J)
2770 OUTPUT A1 ;"AI35"
2780 ENTER A1 ; T(1,J)
2820 REM ENTER A2 ; C$
2821 REM T(6,J)=VAL(C$)
2830 GOSUB 4000
2870 RETURN
2900 DISP "HP85 TIMER 2 NOT FUNC
     TIONING"
2910 DISP "HP85 TIMER 1 NOT FUNC
     TIONING"
2920 OFF TIMER# 1
2930 OFF TIMER# 2
2940 GOTO 2020
3000 GCLEAR
3005 SCALE -6,60,-.3,3
3010 XAXIS 0,2
3020 YAXIS 0,.3
3025 MOVE 3,22.5/25*3
3026 LDIR 0
3027 LABEL "SINGLE CHANNEL REPL
     PROGRAM"
3028 MOVE 3,21.9/25*3
3029 LDIR 0 @ LABEL "----------
     ----------------"
3030 MOVE -4,1.25*3
3070 LDIR 90
3080 LABEL "GRID CURRENT (0-3A)"
3090 MOVE P2+1,0
3091 LDIR 90
3092 LABEL "-----------------
3110 PLOT T(7,1),T(2,1)
3120 RETURN
4000 T(1,J)=INT(T(1,J)*3500  .005
     26*3 4/3.1)/1000
4010 T(2,J)=INT(T(2,J)*510/.020*
     *2)/1000
4030 T(4,J)=INT(T(4,J)*5000  .010
     47)/1000
4050 REM T(6,J)=T(6,J)/10
4053 IF T(1,J)<.49 THEN T(1,J)=0
4054 IF T(2,J)<.17 THEN T(2,J)=0
4055 IF T(4,J)<.69 THEN T(4,J)=0
4056 REM IF T(6,J)<.25 THEN T(6,
     J)=0
4057 RETURN
6500 IF J=71 THEN J=70
6505 W=J
6510 IF J=1 THEN GOTO 6654
6514 PRINT " "
6530 PRINT "TIME (S)     PL /G
       PL.CU."
6540 FOR I=1 TO W
6550 PRINT T(7,I);"   ",T(4,I),"
       ",T(1,I)
6560 NEXT I
6565 PRINT " "
6570 PRINT "GRID CU."
6580 FOR I=1 TO W
6590 PRINT T(2,I)
6600 NEXT I
6610 PRINT " "
6620 GRAPH
6630 COPY
6654 PRINT " "
6655 PRINT "COMPUTER CONTROL SYS
     TEM IS OFF !"
6660 END
7000 DISP "TURN POWER OFF"
7005 U=2000
7006 OUTPUT 714 USING "#,4D" ; U
7010 PRINT "ERROR NUMBER = ",ERR
     N
7020 PRINT "ERROR STATEMENT LINE
       NO. =",ERRL
7030 OFF ERROR
7040 RETURN
```

SHOCK HEATING SYSTEM CONTROL SOFTWARE (SECOND POWER CYCLE)

```
20 REM MENT PROGRAM
21 PRINT "SINGLE CHANNEL REAL P
   ROGRAM "
22 PRINT "----------------
   ------"
23 PRINT "COMPUTER CONTROL S ST
   EM IS ON"
24 PRINT " " @ PRINT " "
25 PRINT "DATE "
26 PRINT "TIME:"
27 PRINT "CHANNEL # :"
28 PRINT "2 nd POWER CYCLE"
29 REM ON ERROR GOSUB 7000
30 REM ON TIMEOUT 7 GOTO 2000
40 REM SET TIMEOUT 7;1000
41 PRINT " " @ PRINT " "
42 DIM T(7,71)
43 P1=121
45 P2=21
46 W2=P2+.5
47 PRINT "POWER SETTING =    ";P
   1
48 PRINT "DURATION =    ";P2
49 J=1
50 A1=709
55 A2=704
56 F1=0
57 F2=0
58 CLEAR
60 DISP "SCANNER - SELF TEST ST
   ART3"
70 OUTPUT A1 ;"ST1"
80 ENTER A1 ; B$
90 IF B$<>"8E8" THEN GOTO 120
100 DISP "SCANNER - SELF TEST PA
    SSED"
110 GOTO 180
120 IF B$="1E1" THEN DISP "CROSS
     GUARD FAILED"
130 IF B$="2E2" THEN DISP "A/D F
    AILED"
140 IF B$="3E3" THEN DISP "HP349
    7A TIMER FAILED"
150 DISP "DO YOU WANT TO CHECK A
    GAIN ? (Y/N)"
160 INPUT A$
170 IF A$="Y" THEN GOTO 50
175 GOTO 6654
180 GOSUB 2020
182 OUTPUT 709 ;"D02,0,1,2,3"
185 W=1
200 GOSUB 2500
210 DISP " "
220 DISP "HEATING CYCLE PARAMETE
    RS:"
240 DISP "POWER SETTING =";P1
250 DISP "DURATION = ";P2
260 A$="N"
270 DISP "DO YOU WANT TO START T
    HE HEATING CYCLE ? (Y/N)"
280 INPUT A$
290 IF A$="Y" THEN GOTO 305
300 GOTO 6654
305 F1=0 @ J=1
306 GOSUB 2700 @ T(7,1)=0
307 PRINT "TURN POWER ON"
308 WAIT 2000
310 GOSUB 3000
320 X=2000
330 OUTPUT 714 USING "#,4D" ; X
335 F1=1
340 S=P1/30
345 BEEP @ BEEP
346 OUTPUT 709 ;"DC2,0"
347 WAIT 10
348 OUTPUT 709 ;"D02,0"
350 SETTIME 0,0
360 FOR I=1 TO P1 STEP S
370 X=2000+I
380 OUTPUT 714 USING "#,4D" ; X
390 NEXT I
400 A=TIME
410 L1=(P2-A)*1000
420 ON TIMER# 1,L1 GOSUB 2920
430 L2=L1+300
440 ON TIMER# 2,L2 GOSUB 2910
450 FOR J=2 TO 70
460 T(7,J)=TIME
470 GOSUB 2700
490 B=TIME
500 IF B>W2 AND F1<>0 THEN GOSUB
     2900
505 PLOT T(7,J),T(2,J)
510 NEXT J
514 W=70
515 GOTO 6500
520 END
2000 PRINT "COMPUTER INTERFACE F
     AILED"
2005 PRINT "TURN POWER OFF AND S
     EE MANUAL"
2010 RESET 7
```

```
2015 F2=10
2017 IF F2=10 THEN GOTO 2920
2020 U=2000
2030 OUTPUT 714 USING "#,4D" ; U
2040 PRINT "TURN POWER OFF"
2042 BEEP @ BEEP
2045 IF F2=10 THEN GOTO 6500
2046 F1=0
2047 OUTPUT 709 ;"DC2,3"
2048 WAIT 10
2049 OUTPUT 709 ;"DO2,3"
2050 RETURN
2500 CLEAR
2510 DISP "FAST INDUCTION HEATIN
     G SYSTEM   CONDITIONS:"
2520 DISP "PLATE CURRENT = ",T(1
     ,J)
2530 DISP "GRID CURRENT = ",T(2,
     J)
 540 DISP "PLATE VOLTAGE = ",T(4
     ,J)
2550 REM DISP "RF POWER = ",T(6,
     J)
2600 RETURN
2700 OUTPUT A1 ;"VR5"
2710 OUTPUT A1 ;"AI38"
2720 ENTER A1 ; T(4,J)
2730 OUTPUT A1 ;"AI36"
2740 ENTER A1 ; T(2,J)
2770 OUTPUT A1 ;"AI35"
2780 ENTER A1 ; T(1,J)
2820 REM ENTER A2 ; C$
2821 REM T(6,J)=VAL(C$)
2830 GOSUB 4000
2870 RETURN
2900 DISP "HP8  TIMER 2 NOT FUNC
     TIONIN"
2910 DISP "     TIMER 1 NOT FUNC
     TIONIN."
2920 OFF TIMER
2930 OFF TIMER
2940 GOTO 2020
3000 GCLEAR
3005 SCALE -6,60,-.3,3
3010 XAXIS 0,2
3020 YAXIS 0,.3
3025 MOVE 3,22.5/25*3
3026 LDIR 0
3027 LABEL "SINGLE CHANNEL REPL
     PROGRAM"
3028 MOVE 3,21.9/25*3
3029 LDIR 0 @ LABEL "----------
     ----------------"
3030 MOVE 10,-.3
3040 LDIR 0
3050 LABEL "TIME (0-60 SEC)"
3060 MOVE -4,1/25*3
3070 LDIR 90
3080 LABEL "GRID CURRENT (0-3A)"
3090 MOVE P2+1,0
3091 LDIR 90
3092 LABEL "----------------"
3110 PLOT T(7,1),T(2,1)
3120 RETURN
4000 T(1,J)=INT(T(1,J)*3500/ 005
     28*3.4/3.1)/1000
4010 T(2,J)=INT(T(2,J)*510/ 0207
     *2)/1000
4030 T(4,J)=INT(T(4,J)*5000/ 010
     47)/1000
4050 REM T(6,J)=T(6,J)/10
4053 IF T(1,J)<.49 THEN T(1,J)=0
4054 IF T(2,J)<.17 THEN T(2,J)=0
4055 IF T(4,J)<.69 THEN T(4,J)=0
4056 REM IF T(6,J)<.25 THEN T(6,
     J)=0
4057 RETURN
6500 IF J=71 THEN J=70
6505 W=J
6510 IF J=1 THEN GOTO 6654
6514 PRINT " "
6530 PRINT "TIME (S)     PL.VO
       PL.CU."
6540 FOR I=1 TO W
6550 PRINT T(7,I);"   ",T(4,I,;"
       ";T(1,I)
6560 NEXT I
6565 PRINT " "
6570 PRINT "GRID CU."
6580 FOR I=1 TO W
6590 PRINT T(2,I)
6600 NEXT I
6610 PRINT " "
6620 GRAPH
6630 COPY
6654 PRINT " "
6655 PRINT "COMPUTER CONTROL SYS
     TEM IS OFF !"
6660 END
7000 DISP "TURN POWER OFF"
7005 U=2000
7006 OUTPUT 714 USING "#,4D" ; U
7010 PRINT "ERROR NUMBER = ",ERR
     N
7020 PRINT "ERROR STATEMENT LINE
       NO. =",ERRL
7030 OFF ERROR
7040 RETURN
```

APPENDIX II

SFCRP - OPTIMIZATION OF THE SHOCK HEATING TECHNIQUE FOR C/T ROLLED JOINT SEPARATION

The following is a list of possible improvements to make the shock heating process more reliable and user friendly.

SYSTEM HARDWARE

1. Redesign of LCT - redesign of the LCT to match the impedances of the selected RF cable and the transmission line for maximum power transfer.

2. Introduction of a power matching circuit at the OTS output to match the impedance of the selected RF cable for maximum power transfer.

3. Evaluation of the long RF cable specification - upon the successful implementations of 1 and 2, an increased system efficiency will result which will decrease the OTS output power requirements, hence the RF cable specification can be modified.

4. Design and build coil head packages to accommodate different reactor channel geometries.

5. Coil insulation - identify a suitable replacement for the glass sleeve and teflon insulator (eg. ceramic) to improve the ruggedness of the head package.

6. Trolley design or a simple robotic scheme - when a suitable long RF cable is selected a lighter and a more mobile LCT-T/L assembly can be employed. A new trolley system or a simple robotic scheme can be developed to simplify the coil insertion process.

7. Simplification of system hardware - the dc power supply, the OTS, the computer control system can integrated into a single unit to simplify wiring and minimize component count.

INSTRUMENTATION & CONTROL

1. RF power metering - state of art RF metering is essential for continuous process control. Reliable metering will result in simplification of system checking procedure (eg. eliminate the "dummy" rolled joint tests in the reactor vault).

2. Shrinkage measuring device in the coil head package - shrinkage measurements can be taken without removing the coil and transmission line assembly from the reactor channel.

3. Fault current protection - if a current short is developed in the system, especially at the coil, LCT, and transmission line, the fault current energy may cause damage to the system and/or the work piece. With a suitable protection system, such damage can be minimized.

4. Temperature sensors - fiber optic temperature sensors at the coil allows temperature measurement to be taken during heating. This will ensure the quality of the separation process. Temperature sensors introduces at the inlet and outlet of the cooling water at the transmission line may provide additional information of the power input to the rolled joint.

5. Real time feedback control - at present, the heating process is controlled by an open loop system. Real time feedback control system will accommodate for variations in field conditions (such as variations in the material properties at the rolled joints).

6. Update the control software to include all the additional sensors and to allow for real time feedback control.

7. Install sensors to ensure proper positioning of the heating coil.